Path Attenuation Estimates for the DPR

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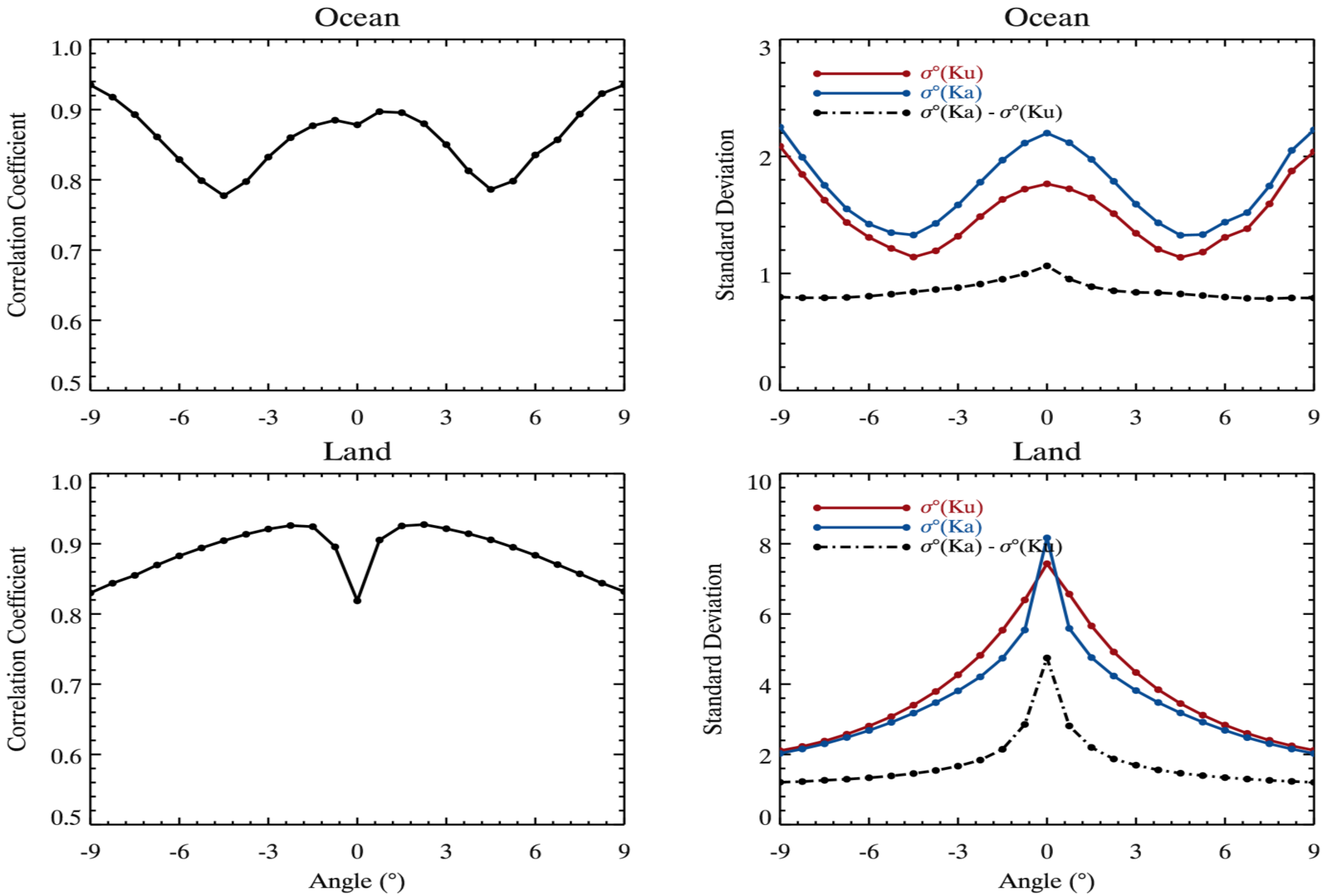
Outline

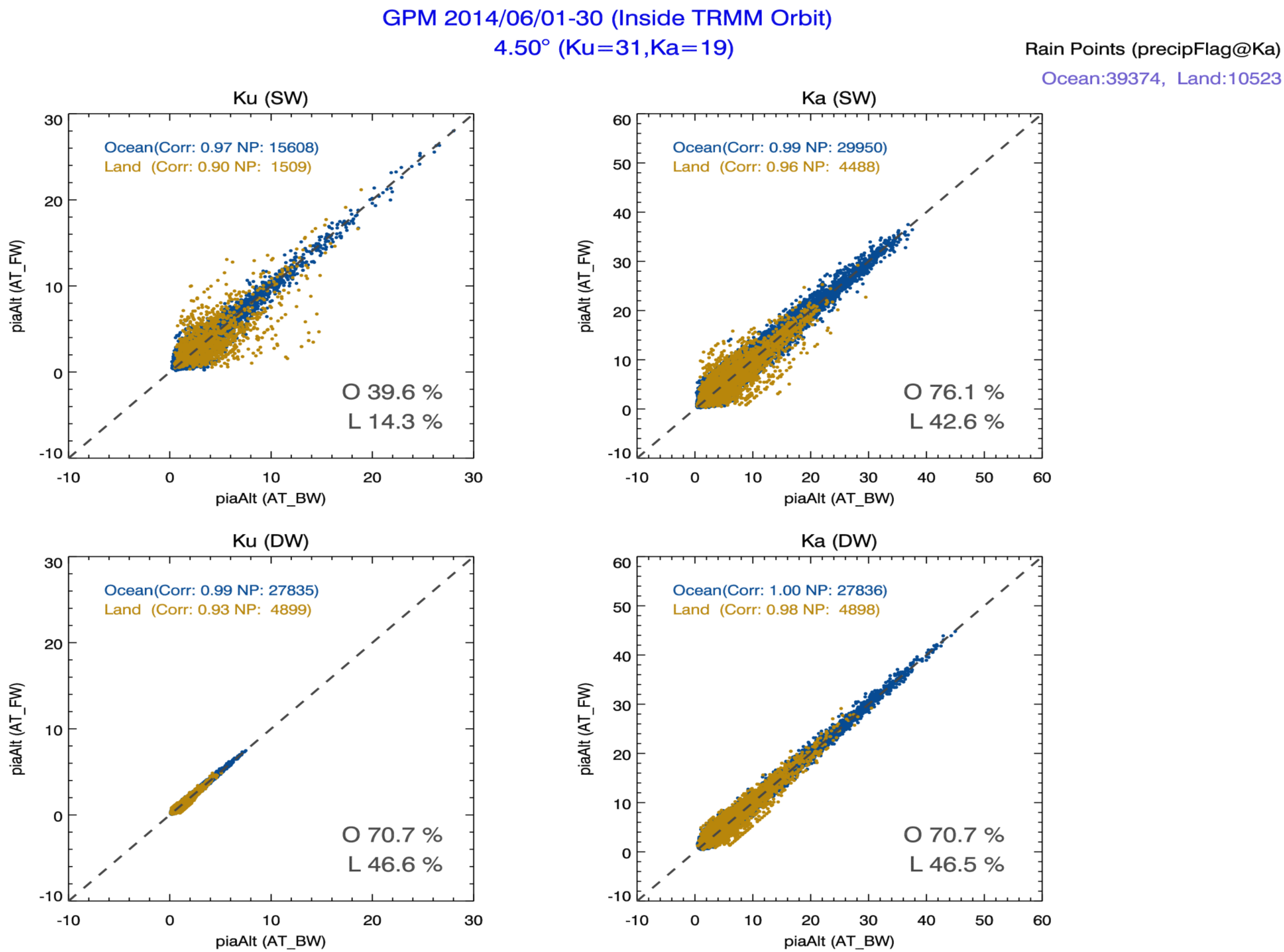
- Overview
- Issues, algorithm improvements
- Summary

Overview

- Results suggest that the dual-frequency version of the SRT is more accurate than its single-freq counterpart
  - Accuracy of estimate is directly related to variance of reference data
  - Variance of [σ^0(Ka)- σ^0(Ku)] is smaller than the variance of either σ^0(Ka) or σ^0(Ku) alone by virtue of the relatively high correlation coefficient $\rho(\sigma^0(Ka), \sigma^0(Ku))$
  - Using different independent reference data sets, we find that correspondence between the various δA estimates is better than that between the various A(Ku) or A(Ka) estimates



SON Statistics

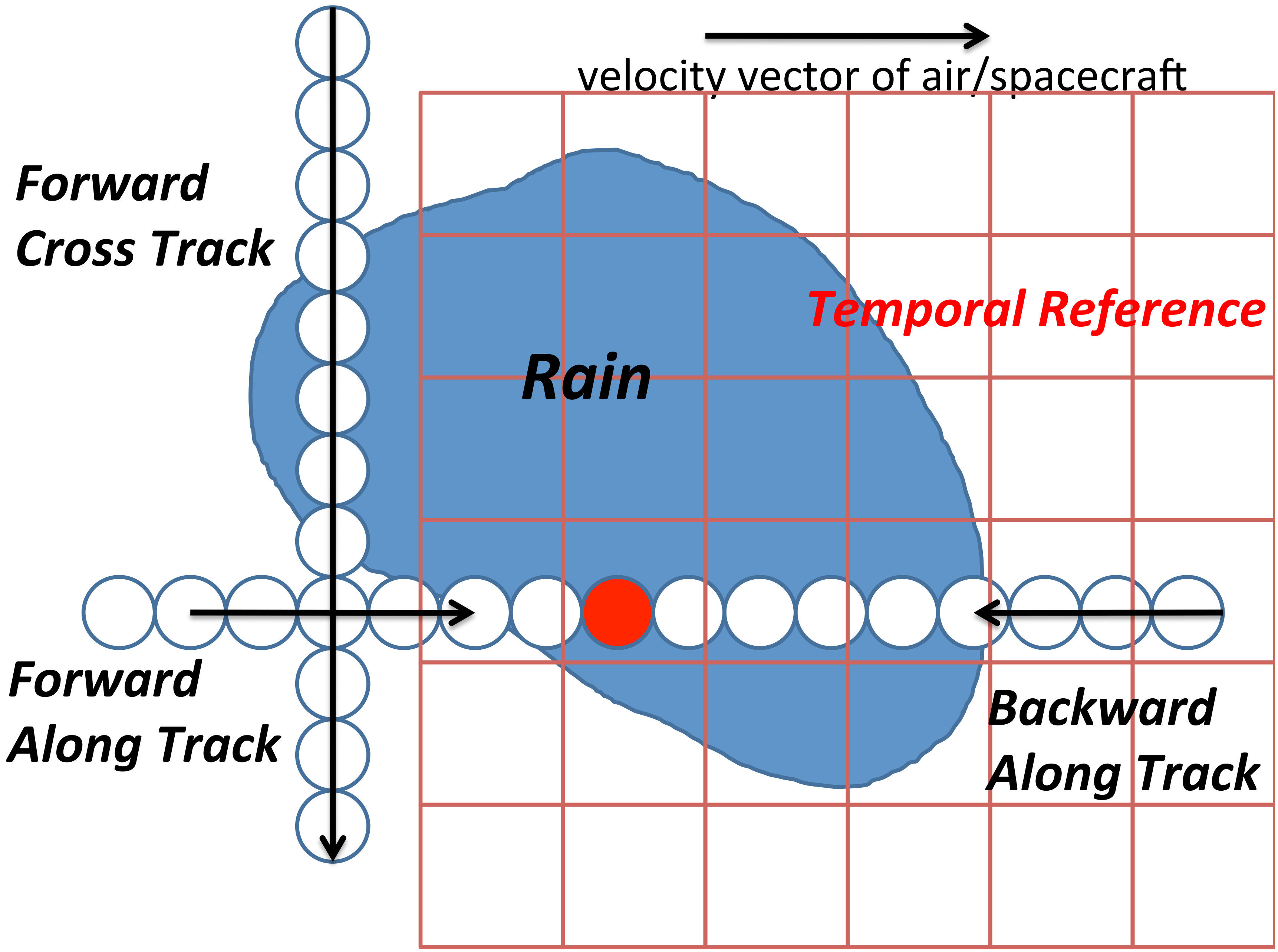

GPM 2014/06/01-30 (Inside TRMM Orbit)
4.50° (Ku=31,Ka=19)
Rain Points (precipFlag@Ka)
Ocean:39374, Land:10523
Ku (SW)
Ocean(Corr: 0.97 NP: 15608)
Land (Corr: 0.90 NP: 1509)
O 39.6 %
L 14.3 %
Ka (SW)
Ocean(Corr: 0.99 NP: 29950)
Land (Corr: 0.96 NP: 4488)
O 76.1 %
L 42.6 %
Ku (DW)
Ocean(Corr: 0.99 NP: 27835)
Land (Corr: 0.93 NP: 4899)
O 70.7 %
L 46.6 %
Ka (DW)
Ocean(Corr: 1.00 NP: 27836)
Land (Corr: 0.98 NP: 4898)
O 70.7 %
L 46.5 %
piaAlt (AT_FW)
piaAlt (AT_BW)

Overview

- However, there are several problems with DSRT
  - The dynamic range is limited to cases where Ka-band signal is detected:
    - Over ocean: 0.4% (nadir) to 0.8% (9^0) of data is missed
    - Over land: 0.75% (nadir) to 2% (9^0) of data is missed
  - Measurements are limited to the inner swath
  - The ratio A(Ka)/A(Ku) = p is needed to convert δA to A(Ku) and A(Ka)
    - DSD data and matching of A_{DSRT}(Ka) to A_{SRT}(Ka) suggests p = 6 is a good approximation
    - Better approximation, based on data, is desirable

Issues/Improvements

- Generation of temporal reference data set
- Use of dual-freq information in outer swath
- Estimating the ratio A(Ka)/A(Ku)
- Direct Validation of the PIA Estimates
- Multi-beam (sub-FOV) & NUBF
- Reduction in variance of σ^0 at near-nadir inc.
- Implementation of wet-surface temp ref data


velocity vector of air/spacecraft
Forward
Cross Track
Temporal Reference
Rain
Forward
Along Track
Backward
Along Track

Temporal Reference Data

- ***Temporal look-up tables***
  - Mean, Std Dev & counts of prior rain-free σ^0 data categorized by location & incidence angle
  - Particularly useful near coastlines, rivers, islands, peninsulas
  - Not implemented in version 3 but will be in version 4

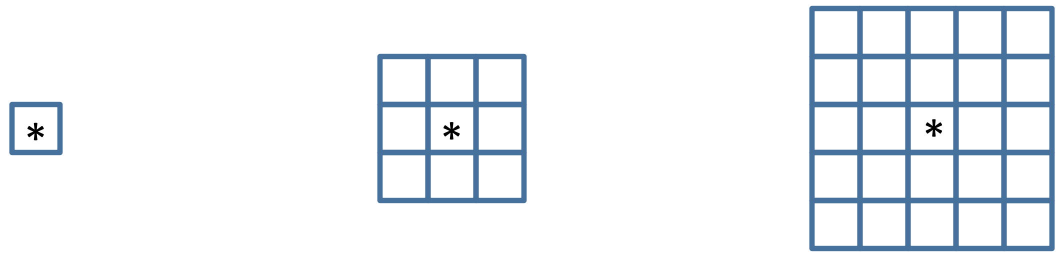
- ***Recalculation of Temporal Files (with latest calibration constants)***
  - Fixed grid, $0.5^0 \times 0.5^0$
  - Four files, separated by season
    - DJF, MAM, JJA, SON
  - Each file comprised of 4 sub-files
    - Ocean, Land, Coast, All
  - Each sub-file contains the statistics of rain-free σ^0 for each of the 'channels'
  - Channels include: Ku, Ka, KaHS, Ka/Ku difference

Temporal Reference Data

- Experiments with variable area-averages
  - Can we reduce the variance of the reference data relative to the fixed area-averaging boxes
  - We use a higher-resolution fixed grid but with variable area-averaging domains
  - the procedure consists of two steps
    - Start with a small area and expand until a sufficient number of samples is obtained ($N \geq N_{th}$) *&*
    - find a local minimum in the std dev (i.e., keep expanding area until std dev begins to increase)
  - We've looked at 3 ways of expanding the area
    - Uniform, Step-wise & Template

Temporal Reference Data

- Uniform
  - Simple expansion from 1 box to 3x3 to 5x5, etc
  - Stop when $N \geq N_{th}$ and std dev is a local minimum
- Step-wise
  - Add one box to the area, at each step, in such a way that the std dev of the data in the enlarged area is minimum
  - Stop when $N \geq N_{th}$ and std dev is a local minimum
- Template
  - For given number of boxes, construct all possible configurations
  - choose those configurations for which $N \geq N_{th}$; among these select the one with the smallest std dev
  - 'template' approach gives the minimum variance configuration but runs extremely slowly for large N



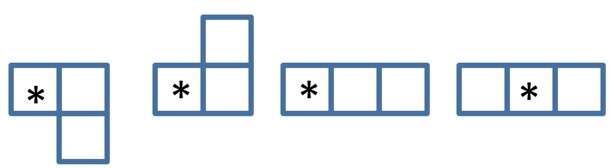
uniform

1 to 2 boxes

5 to 6 boxes

step-wise

3 boxes, 18 configurations

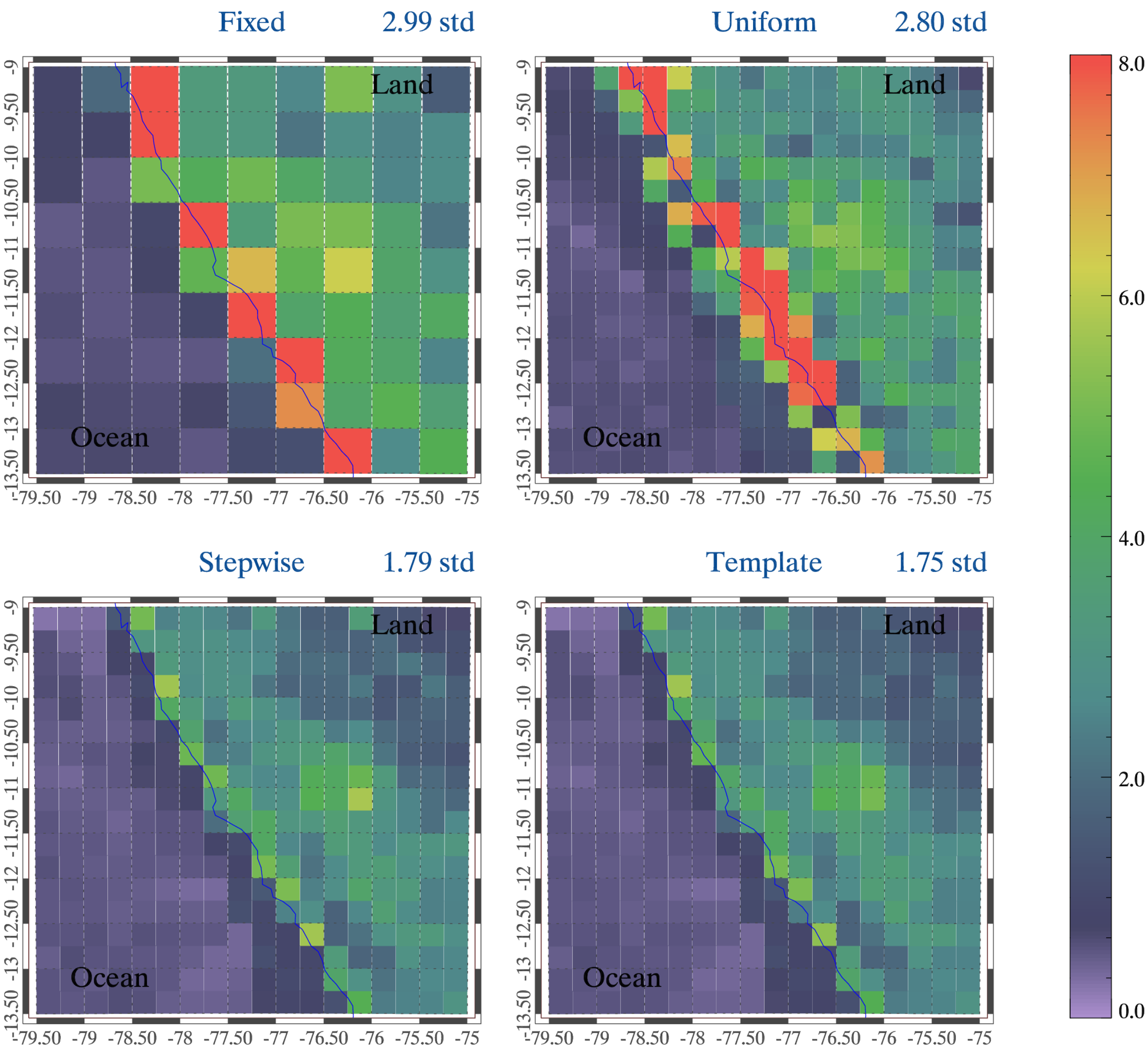


etc.

template

4 boxes, 76 configurations
5 boxes, 315 configurations
6 boxes, 1296 configurations…
9 boxes, 89,190 configurations…

Std Dev [σ^0(Ku)], θ = 3.75°



$4.5^0 \times 4.5^0$ map
Coast of Peru

Fixed grid: $0.5^0 \times 0.5^0$

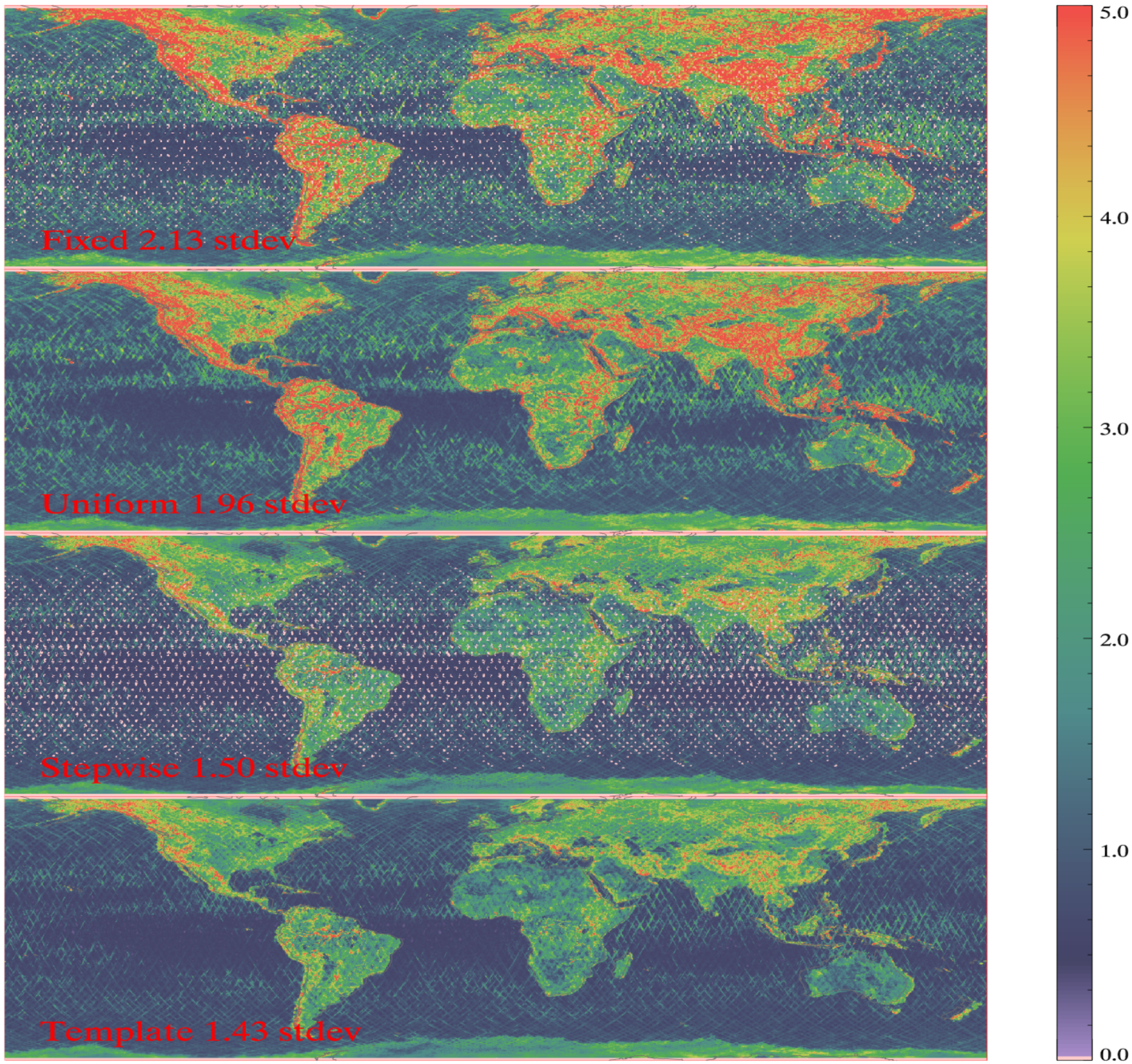
'Variable' grid:
$0.25^0 \times 0.25^0$

No land-ocean-coast separation

Maximum of 6 boxes used for step-wise & template results

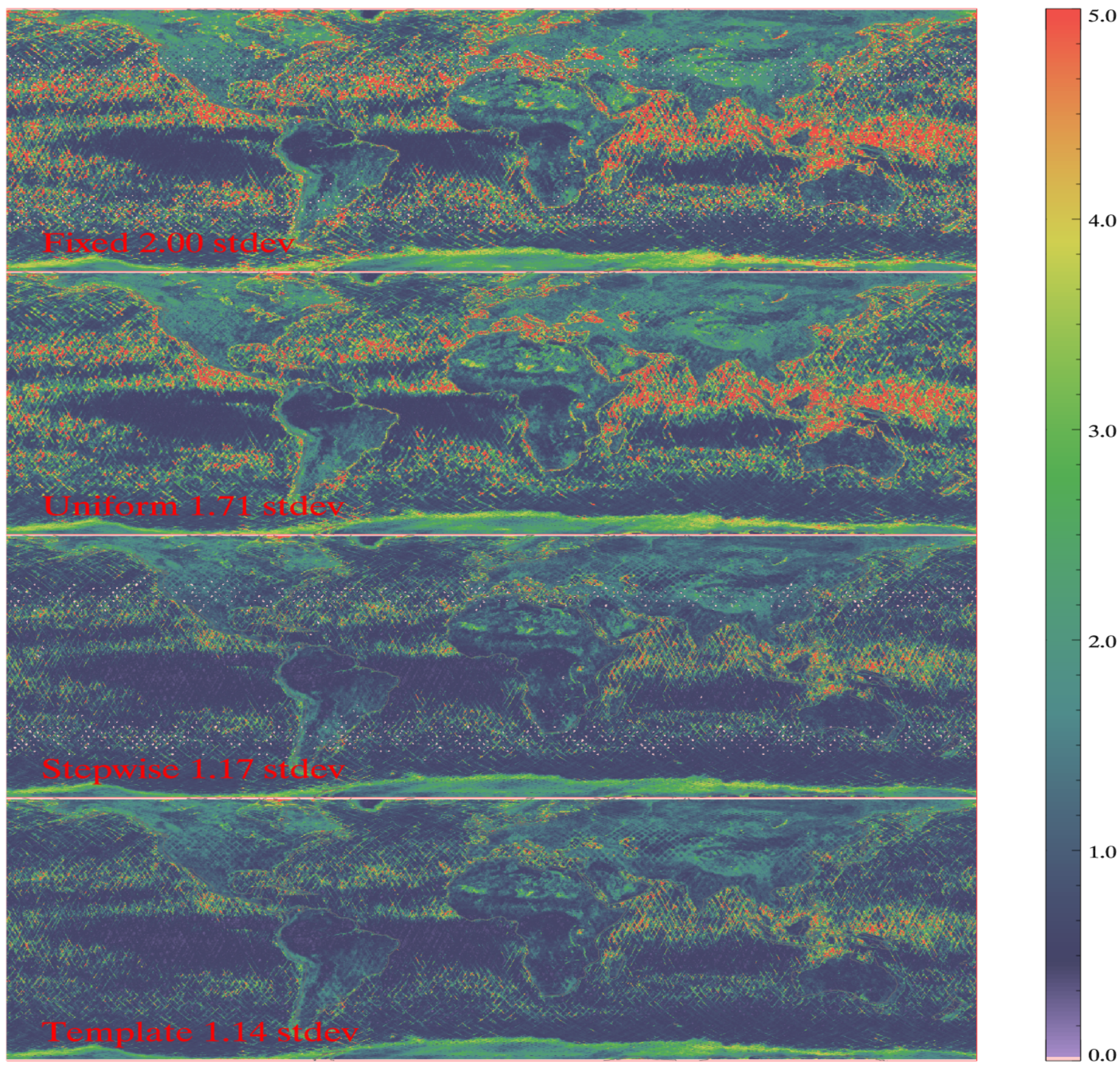
1-Std(temp)/Std(fix)
= 0.41

2014/09-11 Stdev [σ^0(Ku)], $\theta = 0.75°$

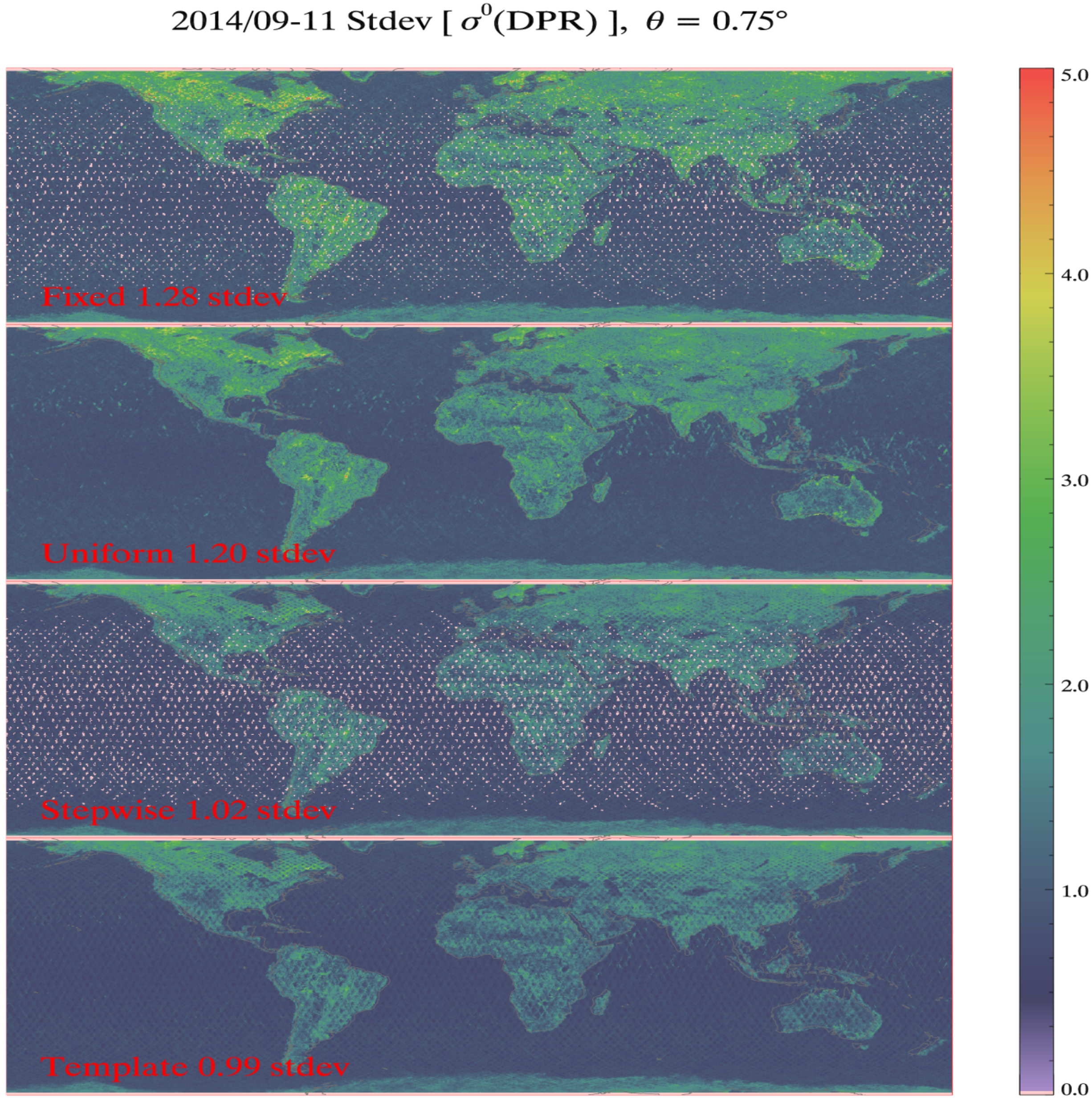


1-Std(temp)/Std(fix) = 0.33

2014/09-11 Stdev [σ^0(Ku)], θ =15.00°



1-Std(temp)/Std(fix) = 0.43



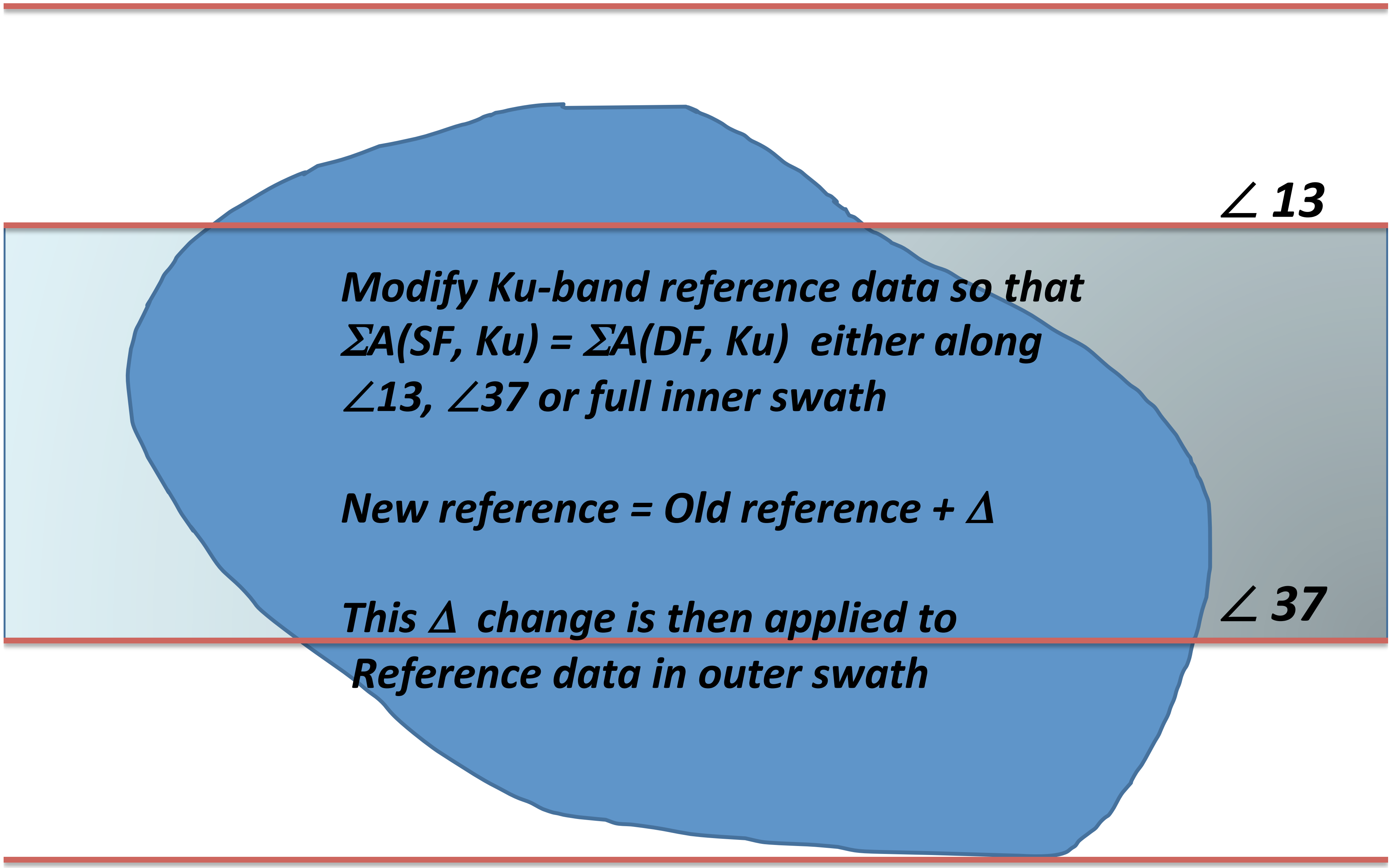
1-Std(temp)/Std(fix) = 0.23

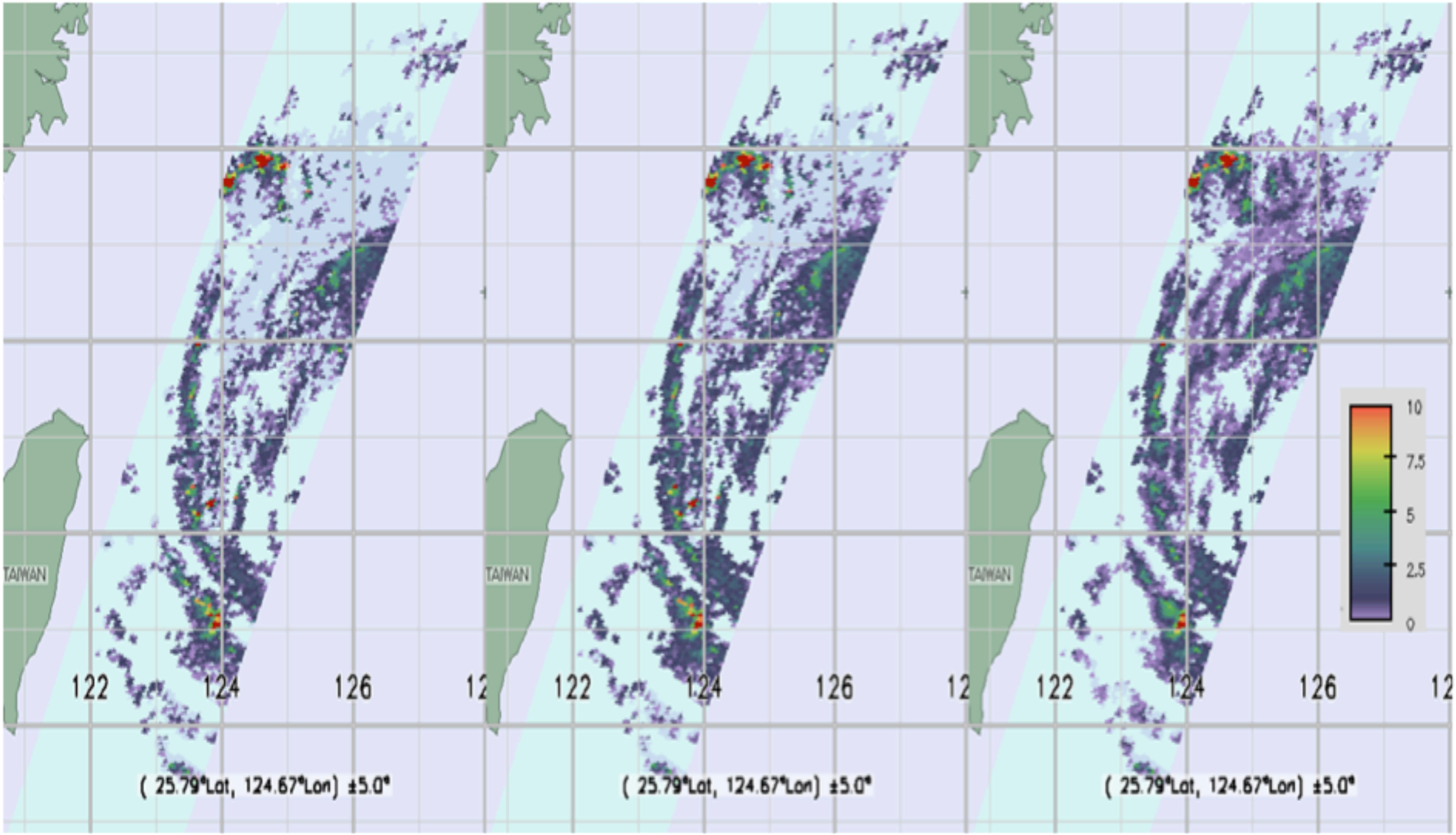
Temporal Reference Data

- It appears that we can decrease average std dev assoc with the temporal reference (at Ku or Ka-band) by about 30-40% (going from fixed to step-wise or template)
- The decrease is smaller for the differential data: about 17-25%
- Many questions to be answered
  - What is the impact on PIA estimates?
  - How do the weights on the temporal change relative to spatial reference?
  - Do we see any minima if we take the step-wise to a much larger number of cells?
  - How do the results compare with other classification schemes?

Use of dual-freq info in outer swath

- As the dual-frequency estimate of A(Ku) is considered more accurate, can we use information from inner swath for the outer swath (OS) path attenuation estimates?
- By matching SRT with DSRT PIA's either at the boundaries (13, 37) or the full inner swath, we can compute an offset to the Ku-band reference
- This offset can be used in the outer swath, providing a modified PIA(Ku) in OS


∠ 13
Modify Ku-band reference data so that
ΣA(SF, Ku) = ΣA(DF, Ku) either along
∠13, ∠37 or full inner swath
New reference = Old reference + Δ
∠ 37
This Δ change is then applied to
Reference data in outer swath



Left: **Single-frequency Ku-band Estimate (full swath)**
Center: **Modified Single-frequency Ku-band Estimate (full swath)**
Right: **'Best Estimate': DF(Ku) estimate in IS; modified SF in OS**
(all estimates are derived from forward along-track ref data)

Using dual-freq information in the Outer Swath

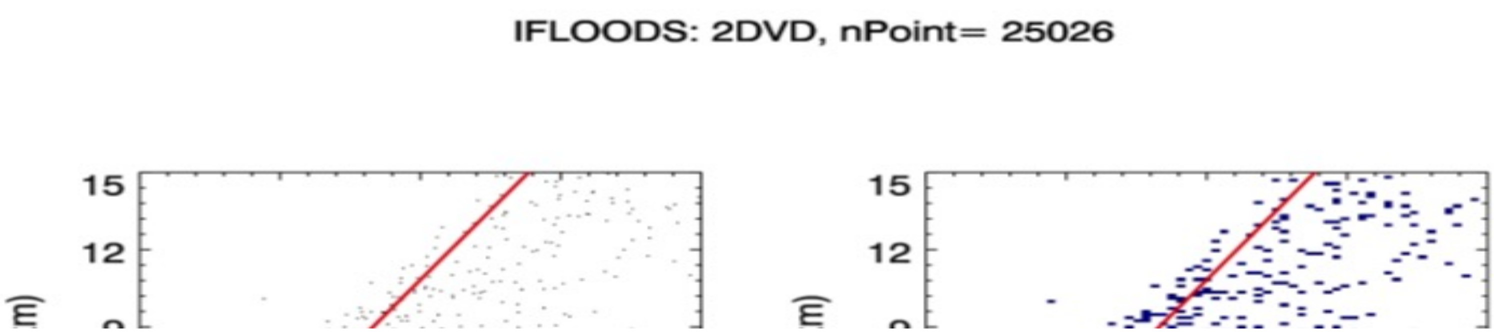
- Although the example shown is encouraging, the examples done to date show varying degrees of success
- The critical assumption is that the differences between the SRT & DSRT seen in the inner swath can be used to modify the estimates in the outer swath – i.e., the biases are spatially correlated
- We need an independent assessment of the results to determine whether the approach is useful

Estimating the ratio A(Ka)/A(Ku)

- Analysis of raindrop size distribution data suggests that p=A(Ka)/A(Ku)=6 is a good approximation
- Also, as DSRT(Ka) depends on p but SRT(Ka) does not: we can use 'good' data to choose p so that the RMS difference between DSRT & SSRT is minimized
  - This also yields $p \approx 6$
- Nevertheless, we would like something better that depends on the actual Z_m(Ku), Z_m(Ka) data

Iowa		Wallops			Swiss
APU	**2DVD**	**APU**	**2DVD**	**Joss**	**Joss**
N=70,186	N=25,026	N=52,521	N=49,898	N=15,273	N=14,978
p=4.84	p=5.41	p=5.90	p=6.68	p=6.44	p=6.34

A(Ka)/A(Ku) Derived from Measured DSD



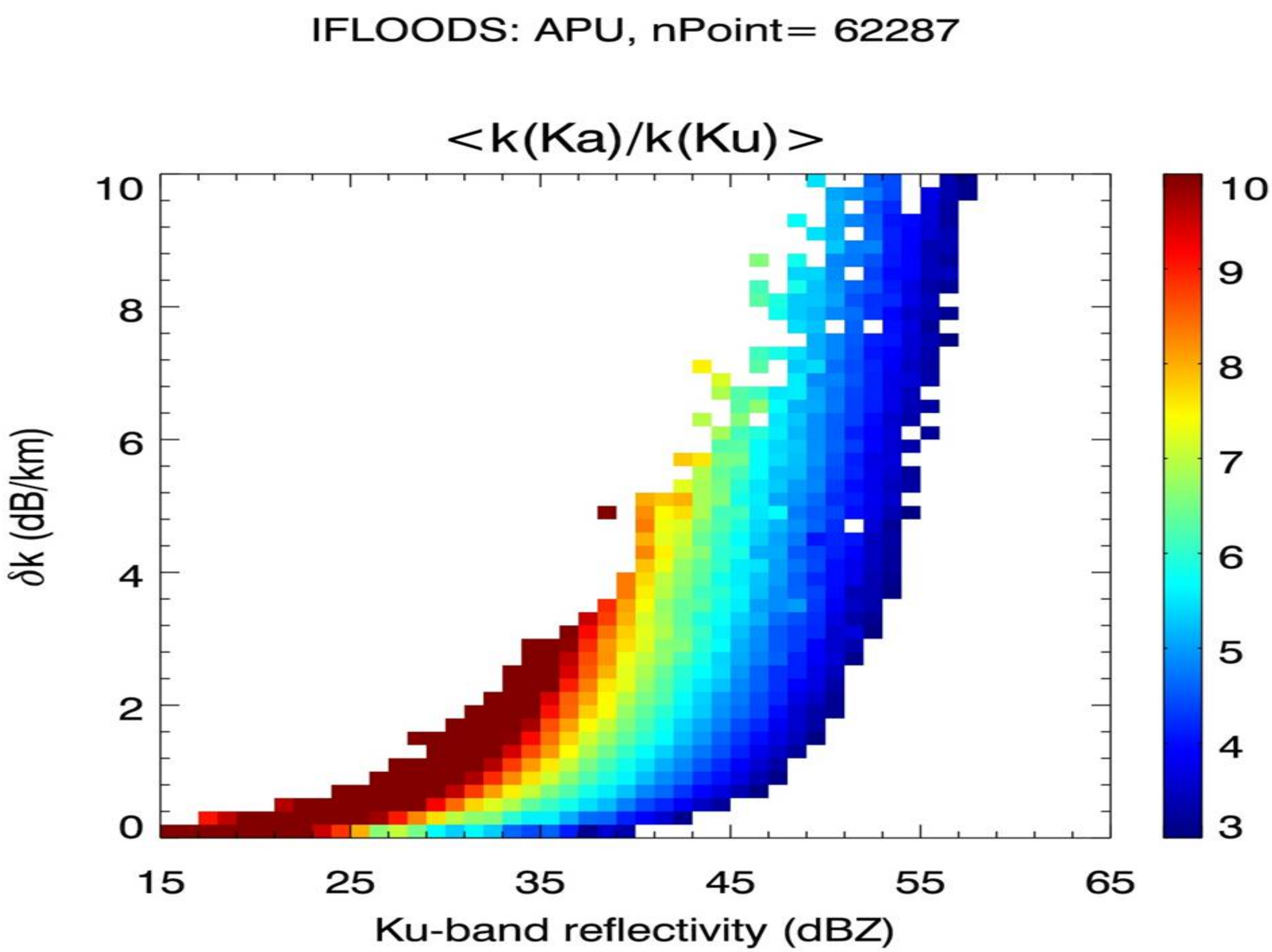
DSD data courtesy of Ali Tokay, Matthias Steiner

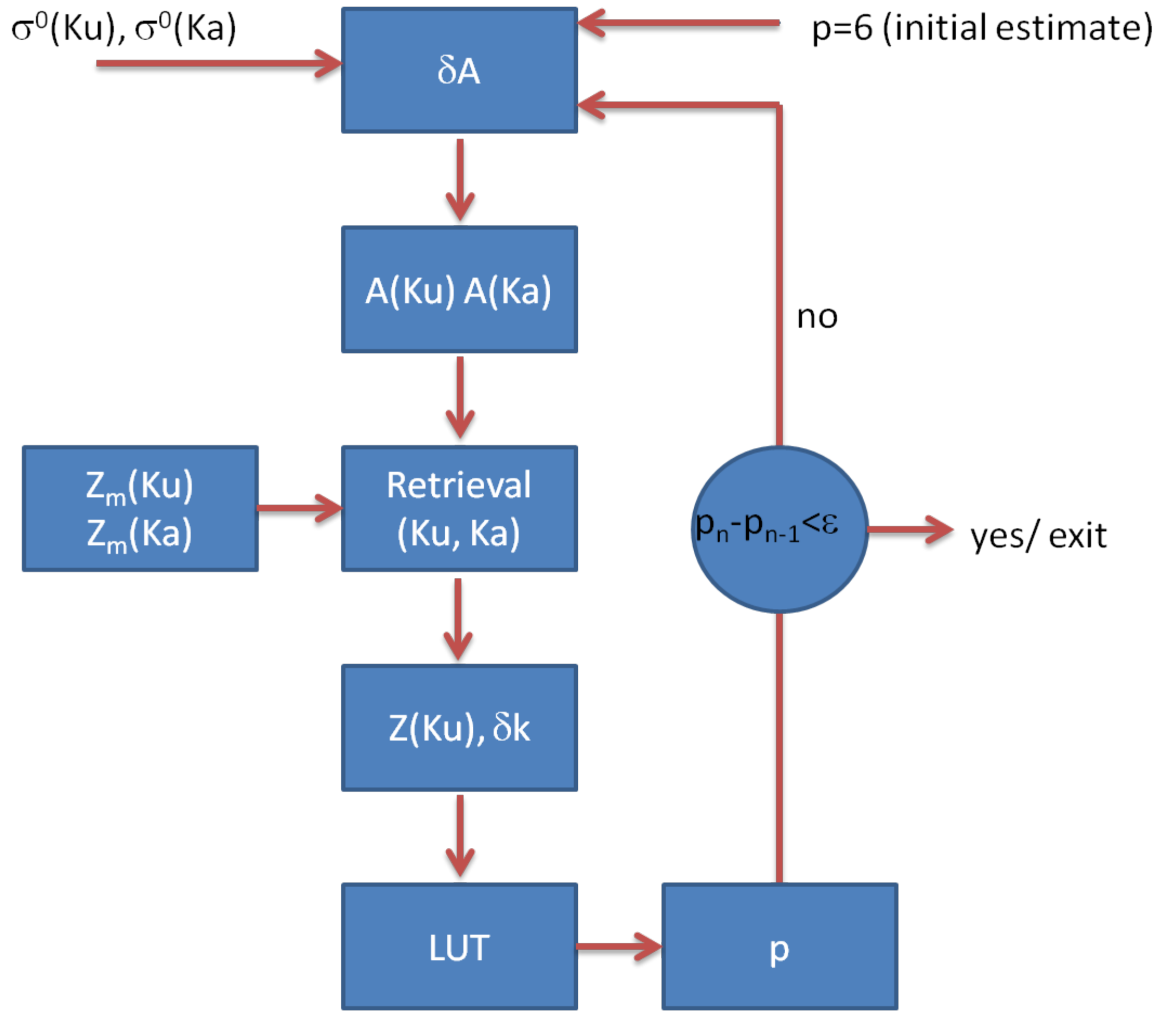
Estimating the ratio A(Ka)/A(Ku)

- Contour plots of p in the δk-Z(Ku) plane suggests that p can be determined if δk & Z(Ku) are known
- However, δk & Z(Ku) are not directly measurable: requires attenuation correction at both freq's
- In principle, the p estimation could be implemented as an iterative procedure

The plot below shows that from $\delta k = k(Ka)-k(Ku)$ and $Z(Ku)$, the ratio p can be estimated

However, what we estimate is δA (the path integral of δk) and $Z_m(Ku)$, the measured rather than the actual Ku-band radar reflectivity

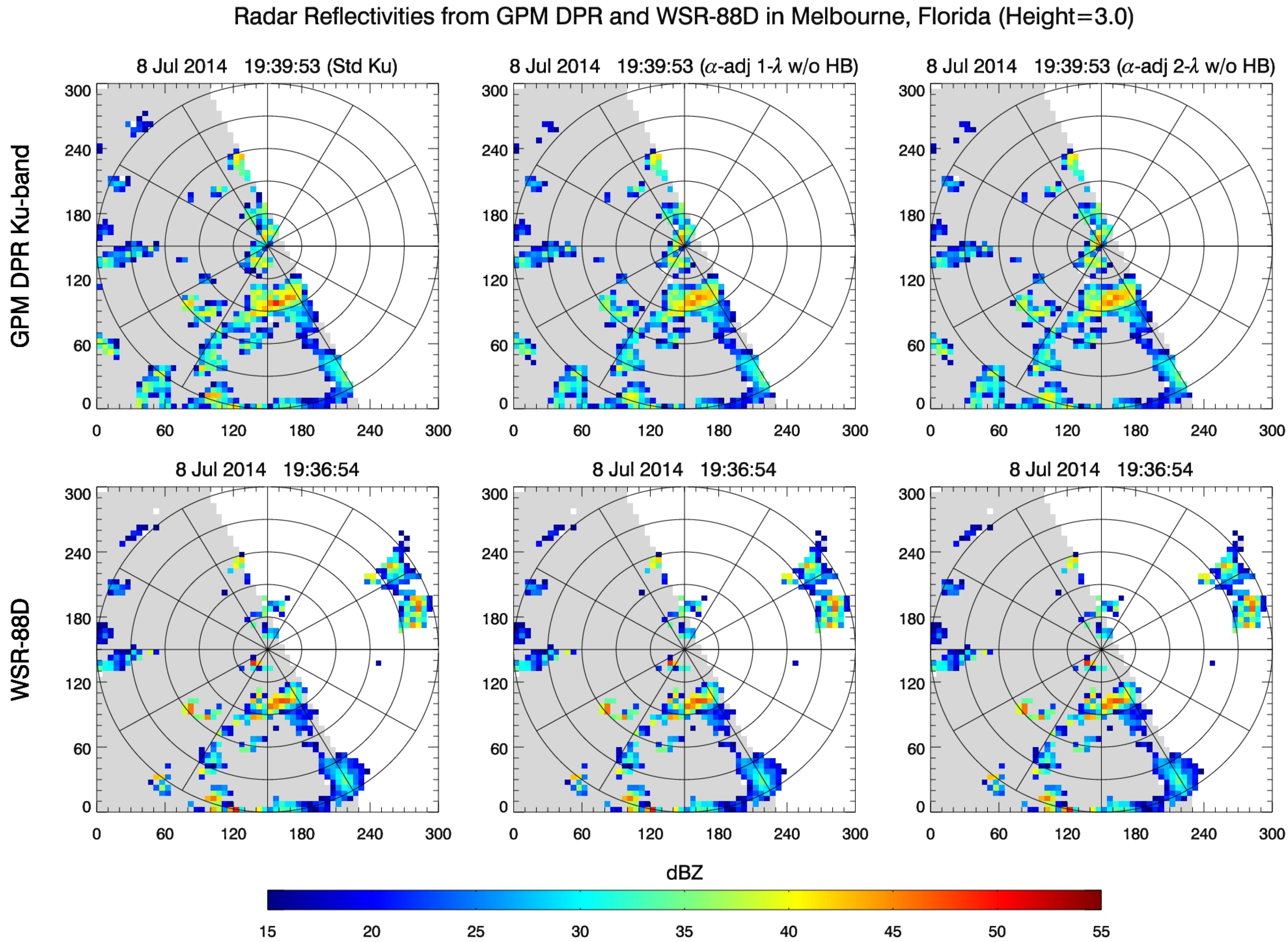




- ***LUT can be derived from results shown in the previous slide***
- ***Retrieval modules for Ku, Ka are needed to convert Z_m to Z***
- ***Whether the procedure converges is not known***

Validation

- ***How can we validate PIA estimates?***
  - Present & past solver modules use both HB & SRT
  - Comparisons of Z(Ku) with Z(S) are effective in validating PIA(final) but not necessarily PIA(SRT)
  - Need a solver module that uses SRT or HB but not both – *this has been done for α-adj & final value*
  - Identify well-calibrated GV radar site(s)
    - Require several years of overpass data
    - Use these data to evaluate SRT & DSRT
    - Also use data to evaluate any change in SRT algorithm



Radar Reflectivities from GPM DPR and WSR-88D in Melbourne, Florida (Height=3.0)
8 Jul 2014 19:39:53 (Std Ku)
8 Jul 2014 19:39:53 (α-adj 1-λ w/o HB)
8 Jul 2014 19:39:53 (α-adj 2-λ w/o HB)
GPM DPR Ku-band
8 Jul 2014 19:36:54
8 Jul 2014 19:36:54
8 Jul 2014 19:36:54
WSR-88D
0
60
120
180
240
300
dBZ
15
20
25
30
35
40
45
50
55

Summary

- **By most measures, the dual-frequency version of the SRT provides more accurate estimates of PIA**
  - Particularly true at Ku-band
- **Nevertheless, there are a number of improvements that would be desirable**
  - Lower variance temporal reference data sets
  - Use of dual-freq information in outer swath
  - Improved estimates of A(Ka)/A(Ku)
  - Use of multi-beam (sub-FOV) PIA estimates for NUBF
- **A more direct validation method is needed to assess any potential improvements**